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ChemEngine: Realizing Entrepreneurship in Undergraduate Engineering Education

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Abstract

A key objective of the Virginia Commonwealth University (VCU) School of Engineering is to link engineering and business education. VCU Chemical Engineering students have launched ChemEngine, a unique, student-run consulting company that provides multiple, fee-based services to chemical, biotechnology, pharmaceutical, and other high-tech firms. Problem solving skills taught early in our curriculum give students valuable and marketable engineering skills after only two years in the program. Our students, with some faculty guidance, are running an engineering consulting practice and working on a myriad of interesting and educational projects.

Appropriate projects for student consultants are generally of the following types: diagnostic, development, or design. *Diagnostic* problems address questions such as "What is the oily material that is contaminating this filter?" or "Why is the flooring material in our factory failing?" or "Why does our fiberglass preform process produce scrap during the summer months but not during the winter?" Almost any phenomenon that needs an explanation fits this ChemEngine project profile. *Development* projects might require a team to collect data on a pilot plant or to determine how fast a carbon filter absorbs odors or to formulate a fire-retardant paint for asphalt-based roofing materials. *Design* projects allow the students to stretch the limits of their training and creativity to, for example, devise a way to produce a microfluidic chip for a biomedical device, create a new digital circuit to operate a micropump, build an instrument to precisely measure the moisture vapor permeability of nonwoven fabrics, or design an ultraviolet sensor for a waste-water treatment system. Our student consultants have worked on all of these problems and others since the company was founded 18 months ago.

Our presentation will describe the business structure and marketing of ChemEngine and offer several projects as examples. However, our primary focus will be on the educational and motivational benefits that accrue when engineering students run their own consulting firm.

I. Introduction - Some History

Early in the summer of 1999, Brad Crosby and Nick Cain, while contemplating how to spend the summer between their sophomore and junior years in college, convened a small group of VCU professors and asked for advice on getting started as engineering consultants. Albeit well aware of their limited training and inexperience, they were nevertheless convinced that problem-solving skills recently acquired as sophomores should somehow be useful and marketable.

Not entirely by coincidence, one of us (Wnek) had been pondering the creation of a student-run technically-oriented business for several years and another (Huvard), aware of the idea and forewarned of the students' intent, had prepared for the meeting by devising a test project with a consulting client in Ohio. The deal was a simple one; the students would attempt to solve a recurring problem in the client's fiberglass composites plant and would be paid as consultants for their work.

The problem involved the generation of scrap from a fiberglass preform oven. In this process, fiberglass is formed into a three-dimensional shape by shooting chopped glass all over a forming mold. The mold has holes in it and slight suction is continuously applied on the inside of the mold in order to hold the chopped glass on the surface. Once formed, the fiberglass mat is sprayed with an aqueous monomer emulsion, the "binder", and then "cured" (polymerized).

The curing process entails heating the preform in a stream of hot air to evaporate the water and raise the temperature well above 100°C to effect the polymerization. The entire curing cycle takes just 50 seconds. If the binder fails to polymerize, the preform never develops the necessary rigidity and must be scrapped. Each summer, the company suffered abnormally high scrap rates due to "mushy" preform side panels and then the problem would disappear as the summer ended. Brad and Nick were to determine the cause of the increased scrap rate and find a workable, cost-effective solution to the problem.

After about two weeks spent studying the process and the curing chemistry, the boys devised a hypothesis. The air for the curing ovens was simply drawn in from outside and then heated. If the summertime humidity increase somehow slowed the evaporation of water from the preform emulsion, the curing process might not go to completion since the temperature of the material could not rise to the necessary polymerization temperature until all of the water boiled away. (This concept comes directly from material on basic phase diagrams in their course on mass and energy balances.) Given the short cycle time, maybe it didn't take much of a change in the curing air water concentration to slow the curing just enough to have an adverse affect.

They then figured out a clever way to test their idea. Obtaining data on scrap production by day for the prior summer, they compared this to data on the daily relative humidity obtained from the weather service at an airport about 60 miles from the plant (see Figure 1). Wow! Every time there was a bump in the local humidity, a bump in the scrap rate at the plant followed. Eureka! A smoking gun!

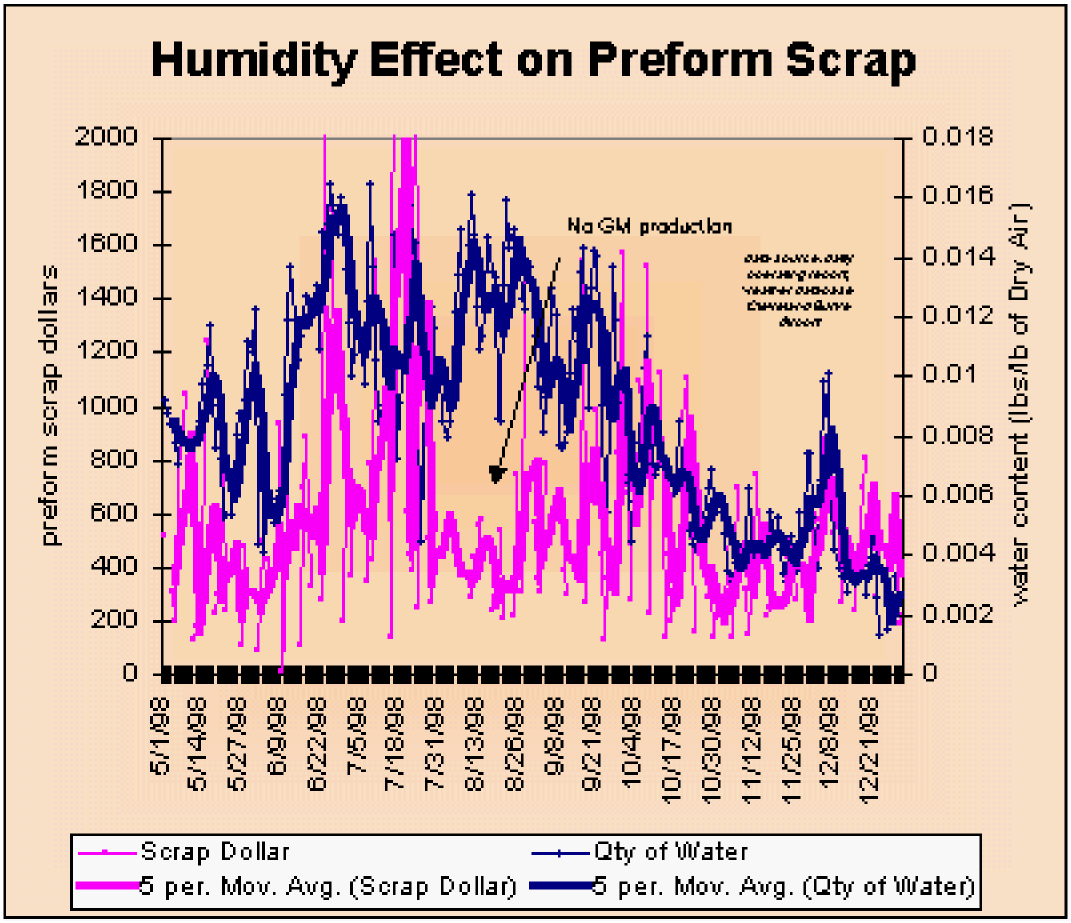

Figure 1: The smoking gun!

Based on these data, they arranged for a plant test. A small amount of steam would be injected into the curing air just downstream of the heater. When steam was injected, preforms were immediately returned with mushy sidewalls. Turn the steam off and the parts returned to their normal rigidity after just a couple of cycles!

This was VERY cool! “What do think we should do now?” they asked. “Well, what have you been taught that chemical engineers ALWAYS do to try to understand a process?” their advisor questioned in response. “Umm, mass and energy balances?” they smiled. “Good idea...I’m glad you thought of that. Go to work and come back if you hit a snag. And bring me one of those burgers next time.”

Several weeks later, after numerous conference calls with plant engineers to obtain data on flow rates, temperatures, compositions etc., then to obtain correct values, then more calls to obtain corrections to the corrections and more corrections to those, they completed a detailed, interactive process flow diagram in Excel. Their simulation of the process took into account water which entered with the air, water which entered with the preform binder emulsion, and water generated from combustion of the natural gas used to heat the air in the direct-fired heating chamber used in the preform oven. Lo and behold! There was a small but definite increase in the average humidity of the curing air when the humidity of the outside air increased to levels typical of the summer months. (Later, in their course on mass transfer, they would be very interested in how the vapor phase moisture concentration affects the movement of water across a liquid/vapor interface. "Oh, so THAT'S why the wet air slowed the curing rate!")

Adding a dehumidifier to the air inlet would work but there was an even simpler, almost free, and somewhat nonintuitive solution. Increase the airflow during the summer! This would actually decrease the overall humidity to levels typical of the winter months by diluting the moisture added by the binder and combustion. In the limit, they correctly argued, the average moisture content would be just that of the inlet air if an infinite flow of air were used. Their solution, when implemented, would save the company the nearly 5 million dollars lost each year to scrap in three plants. ("This mass and energy balance stuff really works, huh?" "Yes. It really works and so does all this *other* stuff I've been trying to teach you.")

Two weeks later, Brad and Nick presented their findings to a room full of enthusiastic plant personnel in an all-day consulting meeting. They presented the work using an illustrated PowerPoint presentation, gave a live demonstration of the interactive Excel simulation, and finished by presenting a written report to the plant's technical manager. Their introduction to real engineering work was complete after two flights were canceled on the way home allowing them to finally collapse in excited exhaustion at about 3 am. ChemEngine was born that night.

Two months later, Brad and Nick were juniors in college and the President and Vice President, respectively, of ChemEngine. New projects were quickly identified and students recruited to work on them, eventually including students from mechanical and electrical engineering. A business structure was created, a standard contract was developed with help from the University's General Counsel, and a web site was started. Standard fees and student salaries were determined and formulas for paying the school for the use of space and equipment were worked out. Accounting procedures were implemented and a bank account was opened. The students would run the business. They would have to learn to manage cash flow and learn when to mail invoices in order to get them in the processing queue so checks would be cut on time. They would have to call accounts payable to get checks in. They would have to decide if and when to spend money for advertising materials and whether they could go ahead and pay a student before an invoice was paid on that student's project. Brad, Nick, and the other ChemEngineers, all full-time undergraduates, were earning real money working on real projects for real companies.

Pedagogical Dissection

Later in the paper, by way of giving instruction on how to start a similar firm at your school, we will describe the business structure of ChemEngine, describe example projects, discuss certain aspects of advisors' roles, and address some of the concerns you will have. Before doing so, it seems worthwhile to examine the first ChemEngine project, determine what Brad and Nick learned, establish how their activities epitomize active and collaborative learning, and report some transcript data which, at least anecdotally, demonstrate the impact such activities can have on your students. While money is usually the primary motivation for students to get involved, the educational benefits will, hopefully, draw some of you into advisory roles and help us realize our long-term goal of helping to create ChemEngine "franchises" at other universities.

In a remarkable series of recent papers [1-6], Felder, Rugarcia, Stice, and Woods have created a roadmap for the renewal of engineering education. Summarizing and reviewing most, if not all, of the relevant references from education literature over the past 25 years, they have created a teaching primer for new engineering educators. They have also saved some of us considerable time; rather than wade through an encyclopedic assembly of books and articles from a quarter century of educational research in order to start learning from the appropriate data and sources, we can read (and reread) the primer.

Rugarcia et al. divide the skills required to address the challenges to be faced by future engineers into seven categories (FEE I):

1. independent, interdependent, and lifetime learning skills
2. problem solving, critical thinking, and creative thinking skills
3. interpersonal and teamwork skills
4. communication skills
5. self-assessment skills
6. integrative and global thinking skills
7. change management skills

The authors draw useful parallels between their classification and that used in ABET Engineering Criteria 2000. Let's examine some of these from Brad's and Nick's perspective and see how project activities addressed them.

Independent, interdependent, and lifetime learning skills are addressed in the context of Perry's[7] model for the transition students make (or we hope they make) as they progress through four years of college. Students generally enter as *dependent* learners; instructors are responsible for helping them become *independent* learners. Independent learners realize that all knowledge is not known and in their texts, that human viewpoints are colored by individual perspectives and agendas, and that they (students) are best served by collecting information from as many different sources as necessary to allow critical evaluation[1].

Brad and Nick were forced to become independent learners in order to complete their analysis of the process. Starting out by relying on flow rates obtained from the plant engineer identified as the "expert" on the process, they soon discovered that the data couldn't possibly be correct. The mass balances simply didn't work with quoted flow rates. More phone calls expanded the information sources. More data, often conflicting, was collected from different plant workers. Data from computer files appeared to have been recorded incorrectly. Bulk densities were offered instead of true densities, confusing the boys and forcing them to the library to find more reasonable values. One fellow, apparently begrudging the decision to allow students to work in his area of expertise, briefly refused to talk with the boys. Often, the most reliable data came from operators - a valuable lesson learned well and early.

Interdependent learning requires that knowledge and attitudes be viewed in context and recognition of the need to obtain information from a wide variety of sources (often non-technical) including peer groups[1]. The power of a team approach to problem solving was strongly reinforced for these two students. At the time, Nick was the stronger of the two technically and Brad both relied on and learned from Nick's abilities with the mass and energy balance calculations. Brad, the more outgoing of the two, served the team well as a liaison to the plant staff, often able to extract information and cooperation from them with nothing more than the force of his friendly personality during telephone calls. The boys developed an "extended" team by seeking out certain plant members for long-distance discussions of ideas. The availability of this resource as a peer group was instrumental in their ability to solve the problem.

It serves little purpose here for us to enter into a debate concerning whether ***problem solving, critical thinking, and creativity*** are innate or learned skills. Either way, there is ample evidence that the development of these skills requires practice - and lots of it. For students given a problem to solve, Rugarcia[1] et al. tell us "they should be equipped to identify the goal and put it in context; formulate a systematic plan of attack that incorporates a suitable blend of analysis, synthesis, evaluation, and problem-solving heuristics; locate sources of information; identify main ideas, underlying assumptions, and logical fallacies, and evaluate the credibility of the identified sources; create numerous options and classify and prioritize them; make appropriate observations and draw sound inferences from them; formulate and implement appropriate measurable criteria for making judgments; develop cogent arguments in support of the validity or plausibility of a hypothesis or thesis; generate new questions or experiments to resolve uncertainties; and monitor their solution process continuously and revise it if necessary." In general, professors may address one or more of these skills in lectures or homework problems but very rarely address them as an interdependent group of skills by working with students on problems which encourage practice on a large subset of them. It is especially difficult to contrive problems that do this, especially if new problems are needed year after year. Real problems surmount these difficulties and there are many hundreds of such problems perfectly suited to the expertise of undergraduate engineering students.

Interpersonal and teamwork skills are required in all ChemEngine projects. In general, the students are responsible for recruiting and forming teams and learn quickly to recruit not only for technical skills but also for the ability to help set and contribute to team goals. The recruiters do not exclude students who have lower GPAs. They have learned that all of their classmates have useful talents. A student who made a C in kinetics might also be a terrific writer and a good team member when report writing time comes around. ChemEngine projects require the students to perfect team skills and the students quickly find it much to their advantage if the workload and thinking are shared. Interestingly, the individual teams that formed early in the endeavor have now coalesced into an organization as Brad and Nick and their peers moved into the senior year. Is this an isolated occurrence or is it to be expected from each group as they move to positions of leadership in the firm? Time will tell.

Obviously, practice on ***communications skills*** played an important role in the first ChemEngine project. Verbal, visual, and written skills were called on both during the project and especially during the consulting trip. Both students learned that the hours of preparation before the trip paid off. They were surprised how smoothly their presentation went and how well it was received. Both agreed that prior classroom practice was a real help.

Written proposals and reports are required for all ChemEngine projects. Some projects require verbal presentations to be given, often as project reviews and usually with PowerPoint. Another area of communications practice generally missing from engineering curriculum is also naturally addressed - the sales pitch. The students quickly learn that getting new business requires sales. Somebody has to talk to potential clients and convince them to part with some bucks for the services offered. ChemEngine advisors play a lead role in teaching sales skills to the students and the idea that, no matter what area of engineering practice they eventually go into, they will always be selling or promoting something; products, services, or themselves. Their long-term marketability, like everyone's, depends in part on this most basic of the communications skills and the entrepreneurial nature of the ChemEngine enterprise requires them to practice it.

Assessment skills received attention in the first project. The boys found it useful to listen to one another and offer helpful advice (as well as raucous criticism) when preparing for that first, all-important presentation to the client. Later, as managers of the venture, they found themselves in the undesirable and often awkward position of having to pass judgement on the abilities and skills of their peers as well as themselves. Peer assessment is clearly part of the management learning process and we are reluctant to remove it from their responsibilities. Advisors must manage this part of the learning process very carefully as students' egos can be quickly and irreparably damaged if attacked too strongly at this age.

The development of ***integrative and global thinking skills*** requires that students be presented with multidisciplinary problems. Again, this is often lacking in engineering courses as Rugarcia[1] et al. point out. Engineering students may see problems in a thermodynamics course as isolated islands having nothing in common with heat transfer or mass transfer problems. In chemical engineering, students see a diagram of a distillation column in the unit operations course, maybe even a picture of the real thing, but once that section of the course is over, they may not see or hear the words "distillation column" for the next two years. Mechanical engineering students will study compressors and blowers but does anyone tell them about the control interlocks needed to ensure that an entire wall of a building is opened prior to starting a giant blower? If the wall isn't opened, the building will collapse as the blower pulls a partial vacuum inside. Brad and Nick learned about this during a tour of their client's facility.

Many engineering professors simply do not have the "generic problem solving skills and integrated and structured knowledge of the engineering curriculum" cited by Rugarcia[1] et al. as a requirement for teaching in an integrated fashion. The problem may actually be aggravated by the movement of many departments to an interdisciplinary faculty comprising engineers, physical chemists, chemists, polymer scientists, and a world-renowned expert on the use of

South African dung beetles for the production of new drugs with recombinant DNA techniques. It seems ludicrous to expect this collection of individuals to maintain detailed knowledge of what goes on in all or even most of the courses. How then can they be expected to integrate the content of their own courses across the curriculum?

Notwithstanding their possibly limited general knowledge of the curriculum, many of these specialists would very likely make excellent advisors for ChemEngine projects - either alone or in groups. The introduction of open-ended, real problems into the curriculum makes the desired connections between the material being taught in various courses and replaces integrated teaching with integrated advising - perhaps a more agreeable task for many. Brad and Nick had to learn and integrate information on mass and energy balances, combustion, blowers, control systems, polymerization chemistry and kinetics, phase diagrams, dehumidification, mechanical properties of composites, mass transfer, heat transfer, computer simulation, and organizational dynamics and politics. They missed out on the dung beetles but a future ChemEngine project may well redress that omission.

Managing change is not a typical part of ChemEngine projects, but it is certainly a skill ChemEngineers must practice. Ours is a company rife with management and employee turnover and the students are acutely aware of their responsibility to help teach and train the next "generation". They have only a very brief period to do so - new generations arrive each September. The survival and growth of ChemEngine is viewed as a legacy and, thus far, the students take it very seriously.

II. Working Methods That Teach

Using a short list from the first of the cited papers, we've described how ChemEngine projects can impact engineering education from the student's viewpoint. Felder[2] et al., in the second paper of the series ("Teaching Methods That Work"), recommend seven teaching methods. The effectiveness of the methods is supported by ample research; those authors cite supporting literature. Here, we reproduce that list with some appropriate word substitutions (theirs are in parentheses) and describe how these methods are applied or simply happen within the context of ChemEngine projects.

1. formulate and propose (publish) clear project (instructional) objectives
2. establish relevance of the project (course material) and advise (teach) inductively
3. balance concrete and abstract information in every project (course)
4. promote active learning during the project (in the classroom)
5. use cooperative working (learning)
6. find (give) challenging and appropriate (but fair) projects (tests)
7. convey a real interest in (sense of concern about) the students' projects (learning)

Students are required to initiate all ChemEngine projects with a written proposal to the potential client. Proposals must examine the problem, offer hypotheses if appropriate, include a ***detailed set of project objectives*** in the form of deliverables, and propose a budget. A well-written letter of transmittal is the price of the stamp needed to mail the proposal. Project objectives are sometimes very much like instructional objectives. “When the project is completed, we should be able to...” or “After obtaining this data, we will calculate...” Objectives are reviewed and discussed to determine if they are 1) achievable, 2) achievable in the proposed time frame, and 3) achievable with available or requested resources. Allowing anything short of these requirements may doom a team to failure just as failure to give them instructional objectives in a class may doom some of them to come up short on course requirements.

Often, the students’ recruiting revolves around convincing other students that a particular project is ***relevant*** to their education and suited to their skills. For example, a project may be described as “just like the stuff you’re already doing in kinetics” or “you’ll be working on the same kind of bio things you told me you want to do when you get out of here”. If these fail, “you can knock down a bill a week on this one” usually works.

The descriptions offered by the students are classically inductive. They describe the physical and chemical aspects of the problem as they understand them, using examples common to the knowledge of both recruiter and the victim. The victim, possibly still with the dollar signs in his or her eyes, generally ticks off a list of the “stuff” they probably need to know in order to solve the problem while consigning items as they are dredged up from memory to columns labeled “I know the heat transfer stuff dead cold”, “I sort of remember that stuff from mass transfer”, or “Geez, I’ll have to go back and review all that stuff I was supposed to learn in thermo”. The recruiter, having practiced the pitch before, reminds the victim that “Bob knows all the thermo and he’s gonna be on the team - we need you for the heat transfer.” thereby relieving thermogastronoma and reeling in the new recruit.

Establishing relevance works. Relevant projects are interesting projects just as establishing the of course material is a prerequisite for keeping students’ interest during lectures and labs.

Obtaining ***balance between concrete and abstract information*** within the context of a ChemEngine project is a consequence of good project choice. Advisors should examine all potential projects for this balance. Felder[2] et al. point out that an abundance of abstract information is usually easy to find in engineering courses; it’s the concrete examples that may be lacking. In contrast, most ChemEngine problems are defined by a list of concrete facts. The students may need help from the advisor to identify the abstract information (theory) pertinent to the problem. This reversal is a useful exercise for the students and one they are rarely asked to do. It is NOT the same as giving them a problem statement and asking them to ferret out the one equation in the text having all the variables including the missing one they are supposed to calculate.

For example, a recent ChemEngine client asked the students to identify a way to prevent cement underlying a tile floor in a prison kitchen from spalling (cracking and breaking into small pieces) after repeated exposure of the floor to steam and hot water from the kettles being cleaned in the room. The concrete facts (ooh..sorry) were the type of cement underlayment and tile, the temperature of the water and steam, and the frequency and duration of exposure. What theoretical information exists that is pertinent to this problem? Is theory related to mechanical stress development with repeated thermal cycling important? How does steam get through the tiles to the cement? Is diffusion theory important here? Why or why not? And so on. The students have to identify such information as a necessary part of proposal writing.

ChemEngine advisors naturally spend time helping the students with their problems. The advisor might begin the derivation of a differential mass balance to help a student get started and then ask the student to finish the derivation. A student with a look of bewilderment brings in experimental measurements because the data don't seem to match the theory ("I thought the concentration was going to go down, not UP"). A short brainstorming session follows. "Tell me exactly what you did and then let's think of as many reasons as we can how something could have gone wrong. Then, you'll have a starting point for sorting this out. Hey, maybe the data are okay and the theory is wrong. Cheer up...you might win a prize or something." Another student comes by the office. This one just broke the client's PLATINUM electrode and the world is about to stop turning! "Hmm. Looks like the little copper wire is just soldered to the platinum thingie. I have a soldering iron in the lab. Ever use one?"

Visits to the advisor's office should <u>always</u> result in an ***active learning*** experience. It doesn't have to take a lot of time. Often, five minutes of discussion or time at the marker board is sufficient for a lesson. In part, this happens because the lesson is related to the project; the advisor gets uninterrupted and complete attention from the student. Try getting the same level of attention in the classroom on a problem taken out of context.

Work on ChemEngine projects occurs in snatches. The workers are full-time students and are allowed to devote no more than 10-12 hours per week to ChemEngine projects. Progress occurs in periodic, short (1-2 hour) team meetings. During a given meeting, the team may develop a flow diagram together or derive the mass balance equations needed or divvy a list of physical properties needed and proceed to find them and then compile a list to hand out. Or, an entire meeting might be devoted to a brainstorming session aimed at devising an experiment to measure the stress-strain curve of an adhesive being heated to 350°C.

These meetings are ***cooperative working*** (learning) sessions. Work on real projects guarantees that the requisite instructional features listed by Felder[2] et al. (FEE II) are involved. There are usually clearly defined goals for the meetings (although sometimes they just get together and schmooze), each team member is responsible for doing his/her share of the work (or they don't get paid), face-to-face promotive interaction always defines the meeting structure (they won't take the time to meet unless they need an interactive group session), they practice interpersonal and teamwork skills (dysfunctional groups don't survive the ChemEngine atmosphere), and they spend time assessing team functions. Assessments are often related to progress on the project and whether all team members are getting their jobs done in a timely fashion. For ChemEngineers, these assessments are critical. Malfunctioning teams don't solve problems, unsolved problems generally means loss of repeat business, and loss of repeat business means loss of revenue. Poor performance translates to reduced income and this is not tolerated. On at least one occasion, the responsibilities of team members have been rotated in order to improve performance.

Felder[2] et al. allude to the following but we'll state it here as a simple fact and let others debate its accuracy. ALL WORK PERFORMED IN INDUSTRIAL SETTINGS IS CARRIED OUT COOPERATIVELY. Companies spend hundreds of thousands of dollars each year providing training to employees on cooperative work styles (teamwork). Cooperative working (learning) works. In industry, being tagged with "not a team player" is death. Your students are terribly ill served if your program provides insufficient teamwork training. If professors in your department find it difficult to learn and implement cooperative learning techniques in the classroom, then find real problems for students to tackle in teams.

Finding challenging and appropriate projects is not as difficult as you might think. All engineering schools have periodic parades of industrial visitors through the hallways accompanied by the requisite meeting with faculty members to discuss ways in which the company can interact (share the wealth) with the school. At VCU, a short description of ChemEngine during such meetings always hits a nerve. Some Presidents and Vice-Presidents view us as low-cost, but satisfying philanthropy, R&D Managers see the cost and quickly figure out how to leverage ChemEngine as a low-cost resource (these are the ones we're after), while company engineers are sometimes amused by the concept. ("Undergraduates? Yeah - right.")

Thus far, we have landed new projects with more than 80% of the companies we've talked to in such meetings. Sometimes, projects find us. The prison floor project, which turned out to be quite interesting and led to yet another project, was initiated by the Warden, figuring a call to an engineering school might turn up someone who knew how to fix problems with cement floors. Since none of our professors happened to major in cement floor technology, the inquiry was funneled to ChemEngine.

It is simply not possible to advise a ChemEngine project and not develop a close relationship with the students. The advisor is part of the team and part of the solution. ***Conveying a real interest in the students' projects*** is an inherent attribute of professors drawn to such a venture. They are also very likely to be teachers who adopt active and cooperative teaching techniques in the classroom. Viewed another way, those now using active and cooperative teaching methods are good project advisor candidates. It is important to remember, however, that ChemEngine is a money-making venture for the students and, while the teaching and learning aspects may be the primary motivation for an advisor's involvement, these are of tertiary importance to the enterprise. The first order of business for clients is solution of the problem they are paying to have solved, and the students are primarily interested in making money by working on engineering problems instead of flipping burgers.

Let us drive home this point. For the 2000 calendar year, the first full year of operation, ChemEngine grossed just under $50,000. That's an impressive achievement for a group of full-time students charging $20/hr for part-time technical work. For some of the students, ChemEngine projects replaced part-time work slinging beers to pay rent. Others were simply drawn to the technical work. While it is very important for the teaching and learning to be a naturally occurring outcome for the students, it must not become the driving force for their involvement or a ChemEngine project will become just another “class”.

Whether or not professors who devote significant time to teaching activities like ChemEngine can be tenured and survive in engineering departments is part of the subject matter covered in the fifth and sixth papers in the FEE series. These two should be required reading for all Department Heads, Deans, and Advisory Board members. In large departments, it is clearly impossible for one person to advise enough projects to involve a significant percentage of the students without completely sacrificing the time that must be devoted to research pursuits. However, the amount of time needed to advise one or two projects would have an insignificant impact on research performance. Is a scenario that has ALL the professors in a department advising one or two projects just too psychedelic to be considered a future possibility?

III. Impact on the Students

The ChemEngine enterprise is still very young and we continue to collect data on the students' performance on projects and on coursework. The data in Table 1 below, though anecdotal, are nevertheless suggestive. The cumulative grade point averages by semester are shown below for two ChemEngineers. The double lines fall prior to the semester that began following first involvement with ChemEngine.

	Cumulative GPA	
	Student 1	Student 2
1	3.0	2.8
2	2.8	2.7
3	2.2	2.7
4	4.0	2.3
5	3.6	1.4
6	3.2	3.0
7	4.0	3.6
8		

Table 1: Cumulative grade point averages for two ChemEngineers.

What made the difference for these two students? Finally understanding the relevance of course work? Increased personal attention from a faculty member? Did acceptance by a peer group whose members made high grades have impact? Did their learning environment suddenly change for the better? Did they respond to the teamwork environment? Did the expectation of performance by their peers and advisors help effect the change?

The answer, according to them at least, is “yes”, meaning all or most of the above. Would the same sort of results have occurred if most of the courses after the double lines were taught using active and cooperative teaching methods? Possibly — but most of their classes were not taught this way. These results argue for early involvement of engineering students in cooperative learning activities.

IV. The Structure of ChemEngine

ChemEngine has thus far had projects that lasted as long as 8 months (and counting) and as short as 4 days. Generally, companies are loath to hire students to perform short-term project work if doing all the paperwork required for payroll deductions etc. is necessary. However, payment of invoices from an established corporation with a federal tax ID presents no problem. The other company is responsible for its own payroll and tax liabilities and the client has an invoice from a registered corporation to document the expenditures as tax deductible expenses.

It occurred to us to incorporate ChemEngine as a non-profit corporation. After discussion with an attorney, however, this did not appear to be a viable or even a good idea. A great deal of paperwork is involved to maintain non-profit status from year-to-year and the local, state, and federal tax collecting agencies are constantly auditing to assure that they haven't missed a potential collection due to some paperwork infraction.

ChemEngine is run as a d.b.a. ("doing business as") of HRC, Inc., an S-Corp originally incorporated by one of the authors for his consulting practice. As such, HRC has a federal tax ID number, pays local business taxes on gross income, and files state and local business tax returns. For the uninitiated, an S-Corp is basically a protective shield. It was originally conceived, in part, to protect the personal assets of sole proprietors from lawsuits over products or services sold by a small business.

S-Corps do not make profits. Some, like HRC, don't even accumulate assets. At the end of each tax year, the difference between the income and expenses of the corporation must be paid to the stockholders of the corporation based on the percentage of stock owned by each. If there is but one stockholder, all such funds are distributed to that person each year as personal income; these monies are subject to personal income taxes. In order that ChemEngine not adversely affect the principal's personal tax liability, it is important that income and expenses closely balance.

The students make money but not profits. Some of the income is returned to the school in the form of payment for the use of space and equipment; ChemEngine has an office at the VCU School of Engineering but it is not a University organization. The students rent the office space and pay to use equipment (e.g., the GC/MS system) on projects as needed. Overhead and equipment and space fees are added to project budgets to offset these costs. The School of Engineering, in turn, uses these fees to help fund student activities. This year, ChemEngine helped fund a trip to the AIChE Annual Meeting for officers of the AIChE Student Chapter. If profit looks unavoidable as the end of the tax year approaches, funds can be donated to the student engineering organizations (AIChE, ASME, IEEE).

Advisors do not receive personal compensation for ChemEngine activities in order that conflict of interest concerns do not arise at the University. However, it is perfectly acceptable for the enterprise to donate funds to an advisor's "Ledger 6" account - one set up, for example, to handle unrestricted grant monies. Such funds remain in the control of the University and are subject to the same spending and auditing procedures that apply to other types of university accounts. The students decide if and to whom such distributions will be made; they have the checkbook. But, distributions must be made no later than December 31 each year. HRC does require one payment from ChemEngine. The parent corporation must pay local business taxes on gross income and ChemEngine income is counted as such. ChemEngine is required to cover the tax liability on gross income incurred by HRC, Inc.

Students are compensated as independent subcontractors. They are not employees of HRC, Inc. Each is responsible for his/her own withholding and income tax liabilities and HRC issues a 1099 form for each student in January of each year. All ChemEngine earnings and expenses are reported through the parent corporation. If one of your faculty members has an existing S-Corp, it can be used to start a ChemEngine enterprise. If not, a business may be incorporated as an umbrella for the company. In recent years, other types of similar corporate vehicles have been developed for small companies which are easier and less expensive to incorporate.

ChemEngineers are responsible for maintaining the financial records of the company and for keeping the checkbook in perfect balance at all times. To aid them, an Excel workbook was developed with a worksheet for each month and a summary sheet linked to the monthly worksheets. Each worksheet contains columns for recording income and the various types of normally incurred expenses. This aids the students in determining how money is being spent and in making income and earnings projections as year-end approaches. Checks are recorded in the both the checkbook ledger and on the worksheets as they are deposited or written and the checkbook is compared to the spreadsheet after each accounting session to verify the balance and correct any errors discovered. The checkbook is balanced against a bank statement each month. Sufficient funds are maintained in the account at all times to prevent bank charges.

Students are allowed to work a maximum of 10-12 hours per week on ChemEngine projects during the academic year. During the summer months, students may work a full 40-hour week. All engineering students are required to complete an internship with an outside company during the summer between the junior and senior year. Several companies in the area have found it convenient to sponsor an internship through ChemEngine. The firm typically charges $20/hr. for student services and pays $10-$12.50/hr. ChemEngine officers are compensated for the time they spend running the company. All ChemEngineers are expected to help with advertising and with staffing booths during open houses at the school and for any shows or company functions they are invited to attend.

Time sheets must be turned in to the Financial Officer every two weeks. Invoices to clients are typically mailed around the 20th of each month and are payable on a net-30 basis. Many large companies do check runs around the 24th-26th of each month. The students are taught to get their invoices out and into the processing queue in order for the payment checks to be cut during the following month's run.

Some projects are done at the School of Engineering, others are done on-site at a client facility. Students negotiate travel compensation as part of their work contract. ChemEngine occupies a small office at the School of Engineering. The office is equipped with four computers, Internet access, a laser printer, a telephone, a copy machine, and some small filing cabinets. A marker board and shelves containing extra textbooks, journals like CEP, catalogs, current copies of the Chemical Marketing Reporter, and whatever literature on jobs and internships is floating around complete the setup. Seniors in Chemical Engineering and all students currently working on a ChemEngine project are given access to the office. The office is the focal point for work sessions and, of course, for hanging out between classes.

V. ChemEngine Projects

All ChemEngine projects, however large or small, require a contract signed by an appropriate officer of the client company. Our standard contract was developed with assistance from the University General Counsel and a copy can be supplied on request. The contract requires client firms to indemnify the University, the Commonwealth of Virginia, and HRC, Inc. for work performed by ChemEngineers. The companies hire the students for their own benefit and at their own risk.

Notwithstanding any indemnification, the liability issue is handled in large part by judicious choice of clients and projects. Projects requiring inherently dangerous work are unacceptable, of course. Handling nerve toxins or explosives would be extreme examples. When students work on-site at a client facility, the client contractually accepts liability for the student consistent with the same liability incurred if the company hired the student as an intern or a co-op. It may also be possible and wise to purchase a liability insurance policy for the corporation. For example, AIChE offers low cost (about $600/yr) $1MM liability policies to small consulting firms run by members. Regardless of protection levels and indemnification clauses, there is always some level of risk attached to engineering consulting work. It is part of any service-oriented entrepreneurial activity and must be carefully considered and carefully managed.

Companies that place extreme demands on the students' work schedules or on the completion time allotted for a project will be rejected. The students are taught the importance of maintaining a sense of urgency concerning a client's project but they are still students – studies always take precedence. If, for example, a new client proposes a project that requires the students to work during exams, the project will be rejected.

Advisors must also manage intellectual property issues. Students are legal adults and are allowed to sign nondisclosure agreements after some discussion of their responsibilities in doing so. However, ChemEngine cannot enter into contracts that assign intellectual property rights to clients; if University personnel are involved in the invention process, those rights belong to the University. This necessarily creates an inescapable conflict-of-interest for ChemEngine advisors. To circumvent the difficulty, ChemEngine simply does not contract projects that have an obvious intellectual property component. Such projects must be handled as sponsored research programs requiring a legal contract between the client and University. Obviously, the potential exists for discoveries to be made during a project that initially seemed unlikely to spawn intellectual property; a risk we attempt to minimize but necessarily and willingly accept.

A list of short project descriptions follows. These are intended to convey a sense of the type of projects that are suitable for undergraduate engineering consultants. All were (or are) real projects.

- A national environmental consulting firm located about 100 miles from VCU asked ChemEngine to run a waste-water treatment pilot facility at a local chemical plant. Four students ran the pilot facility, kept the pumps working, collected and labeled samples, and ran a series of four 2-month long experiments. The original study plan called for collecting two months of data. The funds saved by employing ChemEngine student consultants were sufficient to extend the study to eight months.

- A local chemical company needed an inventory of their laboratory chemicals. A ChemEngine consultant, although unhappy about doing such a mundane chore, took the contract to establish a working relationship with the company. The company, after seeing the student work, offered to sponsor the student's summer internship through ChemEngine. The student spent his internship modeling the behavior of an industrial cooling tower.

- A local chemical equipment company wanted to develop a system to monitor the aging of UV lights in their industrial units. A ChemEngine team surveyed the literature and developed a list of sensors having potential for the application. One of the students went on to do a summer internship with company during which he built and tested the sensor system.

- A domestic appliance manufacturer was developing a personal air filtration appliance. They wanted to know how various candidate filter materials (activated carbon etc.) performed when exposed to pungent synthetic smells (with names like "foot odor" and "bathroom odor"). They also wished to know what chemicals were in the stinky mixtures (for reasons still unknown). A ChemEngine student used GC/MS to identify a number of the mercaptans and organic acids in the mixtures. She and a teammate devised and carried out a series of experiments to measure the absorbance of the various filters when exposed to the stinky stuff.

- A boat manufacturer received a complaint from a customer who claimed the air-conditioner on his new boat was defective. An oily sample of fabric was offered which was claimed to have been over the outlet of the AC unit. A ChemEngine team devised a method to extract and analyze the oils using GC/MS. The data suggested the presence of diesel fuel. The students placed similar rags over the exhaust pipes of a friend's diesel truck and analyzed that sample as well as a sample of the diesel fuel. A "fingerprint" match to the original GC/MS data was obtained. Apparently, the exhaust fumes from a nearby diesel engine were being sucked into the air-conditioner intake.

- A firm that manufactures asphalt-impregnated roofing panels wished to find an inexpensive way to flame-retard the panels and expand their market. A ChemEngine team designed and built a burn chamber and set about modifying the paint used on the roofing panels to make it flame-retardant. Adding a mixture of emulsion poly(vinyl chloride), sodium bicarbonate, and powdered sugar provided an excellent intumescent (self-bubbling) char that improved the burn performance of the panel to levels previously provided only by expensive additives. Unfortunately, exposure to the hot summer sun caramelized the sugar and made the roof panel pretty sticky. This also caused lots of bugs to stick to the panel. The students have decided they are on the right track, however, and are proceeding to test combinations of molybdate additives and PVC. The molybdate additives were identified from the literature as causing PVC to char, hopefully negating the need for the sugar.

- The kitchen floor of a regional prison was spalling due to steam and hot water exposure (we talked about this one a bit before). The ChemEngine team visited the prison and returned to identify the cause of the problem and propose a solution. They found a small company that sold a poly(methylmethacrylate)/concrete floor composite which was cast and polymerized in place. The product was meant specifically for such applications. The students tested this product and several other similar flooring products by casting the materials on 4”x4” concrete blocks and then subjecting the blocks to boiling water followed by immediate freezing. This cycle was repeated dozens of times on each sample and the performance compared. The product made by the small company performed admirably; others did not fare so well. A report with pictures was submitted to the Warden and the owner of the small company got the replacement contract.

- The students then proceeded to sell the owner of the small company on the idea of building a database of regional commercial construction firms involved in building prisons, hospitals, schools, etc. They also devised and sold the owner a plan to produce a web-site and to develop some case study “cut sheets” for use in mailings to the firms they would put in the database.

- A small local company produces an instrument that uses biofeedback to teach children with attention deficit disorder how to concentrate. The device uses electrodes filled with a conductive gel as a means of sensing brainwaves. The company wishes to improve the conductive gel being used and improve the lifetime of the electrodes. A ChemEngine team is currently collecting gel-producing materials and equipment to measure conductivity in order to implement the experimental plan devised for the client.

ChemEngine exposes students to real engineering and business problems. As a vehicle for cooperative learning, the enterprise may be unparalleled. ChemEngineers are exposed to lessons which cannot be taught adequately in a classroom setting, they learn engineering and business skills through actual practice, and they develop outstanding teamwork skills. Overall, ChemEngineers are better prepared to enter the workplace after graduation than would otherwise be the case. There is also evidence supporting our belief that involvement in the activity can have a profoundly positive influence on academic performance.

Starting an undergraduate engineering consulting firm does not have to be an overwhelming, daunting, or terribly time-consuming task. Like other entrepreneurial activities, it takes planning and a small group of dedicated workers to launch. The business structure adopted will depend to a large degree on the university and departmental environment. This activity, like any other, may be unsuitable for all programs. However, if your program does embrace the concept and would like to start a similar venture, ChemEngine's students and advisors will be most happy to help you in every way possible. Come join us!

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Brad Crosby earned a B.S. in Chemical Engineering from VCU in Spring, 2001. He co-founded ChemEngine in the summer of 1999 and served as President through spring, 2001. Brad has accepted a position with a major microelectronics firm.

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Nick Cain will earn a B.S. in Chemical Engineering from VCU in December, 2001. He co-founded ChemEngine in the summer of 1999 and served as Vice-President through Spring, 2001. Nick will attend graduate school in chemical engineering after graduation.

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Julia McClees will earn a B.S. in Chemical Engineering with a minor in Business from VCU in December, 2001. She served as Marketing Manager and Financial Officer of ChemEngine from Spring 2000 through Spring 2001. Julia intends to take an industrial position after graduation.

JASON BARA
Jason Bara will be a senior in Chemical Engineering at VCU in Fall 2001 and will serve as President of ChemEngine for the 2001-2002 academic year. He has already completed several ChemEngine projects and plans to attend graduate school in chemical engineering after graduation.